Taking Shadow Prices Seriously: The Value of Environmental Amenities Implied by NeoClassical Economic Growth Theory

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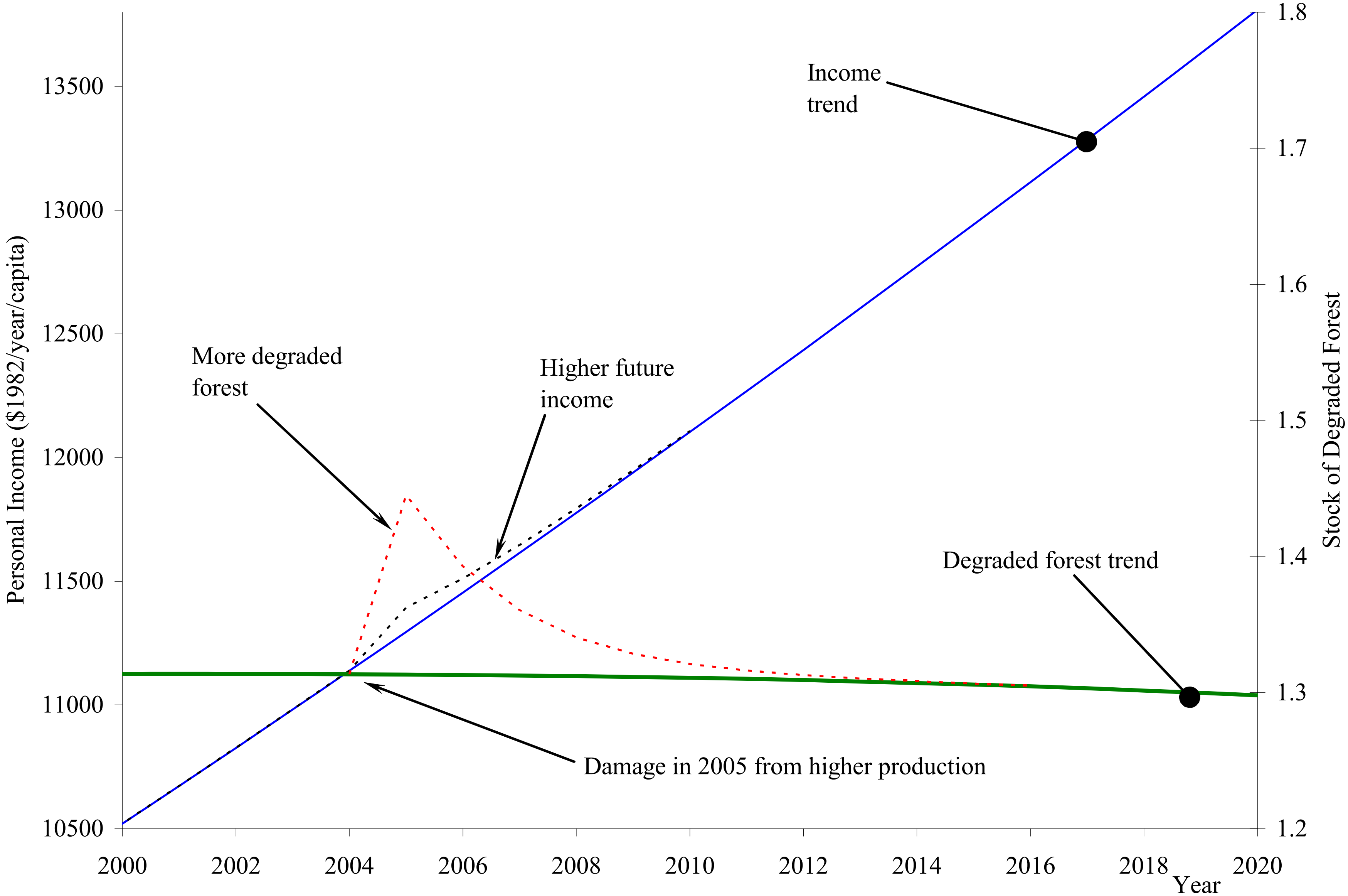
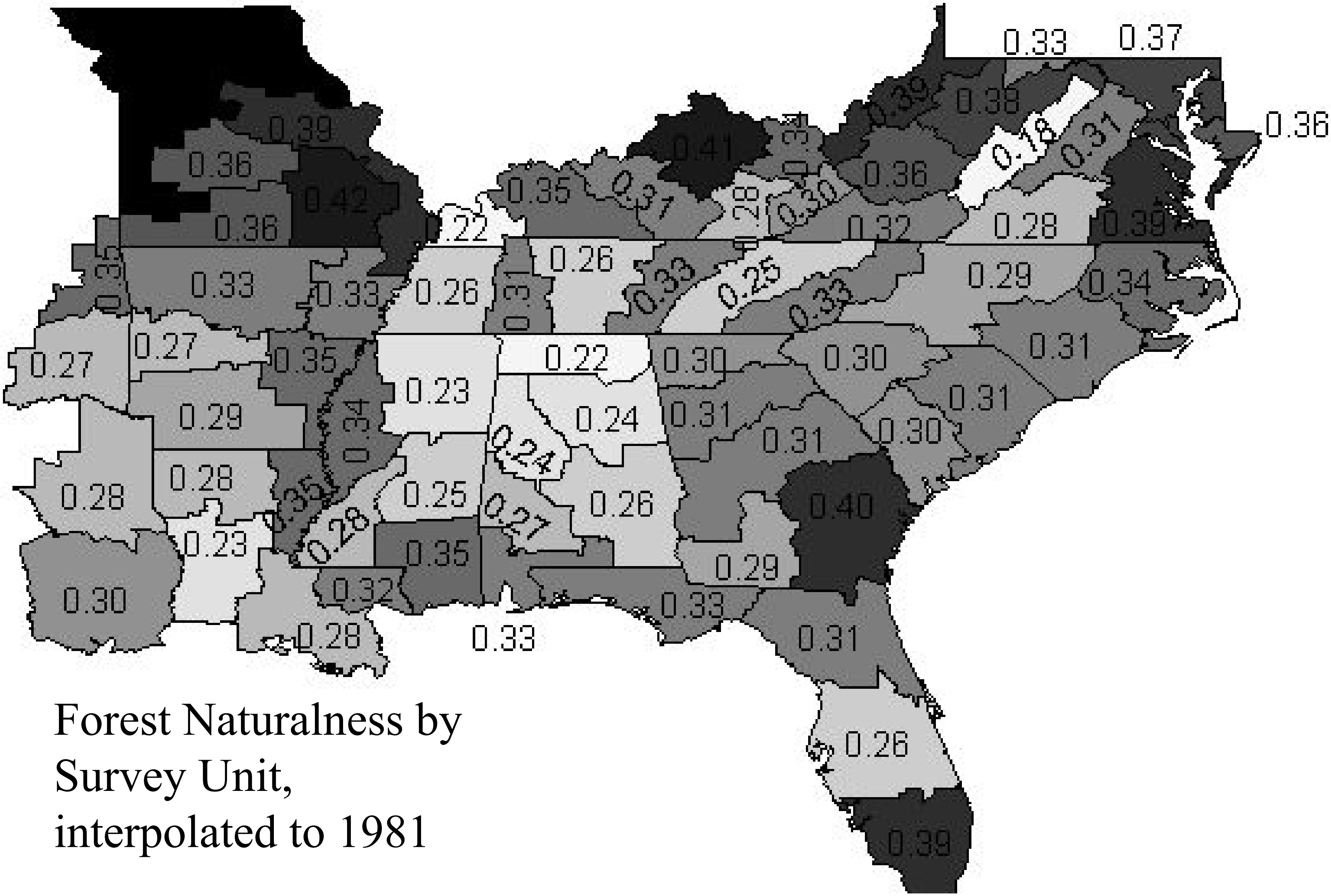
Shadow Values/Prices

- Extra utility from relaxing constraint
- For growth model
  - Constrained by future resources
    - Capital
    - Forest

Economic Growth

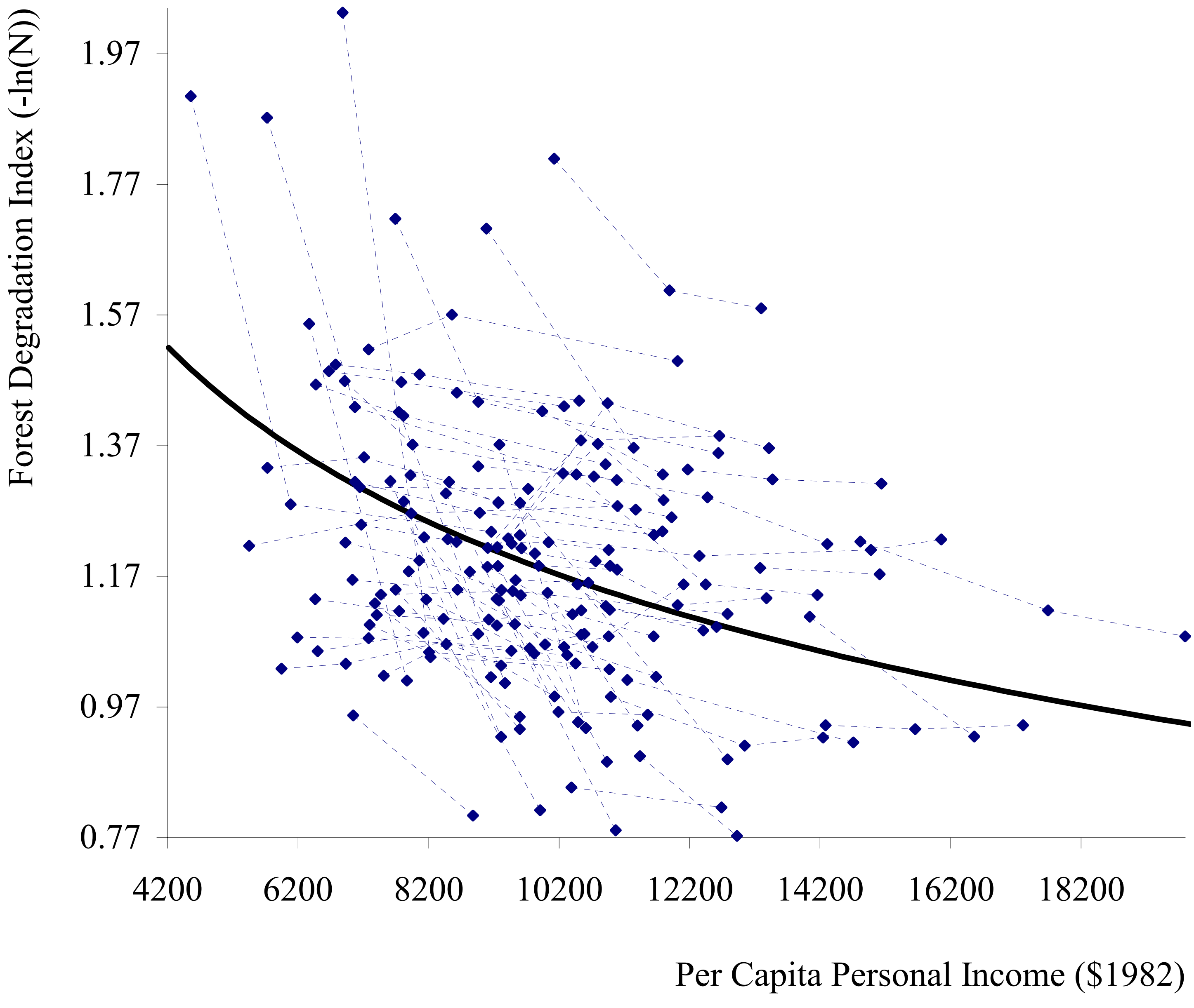


Forest Landscape Assessment

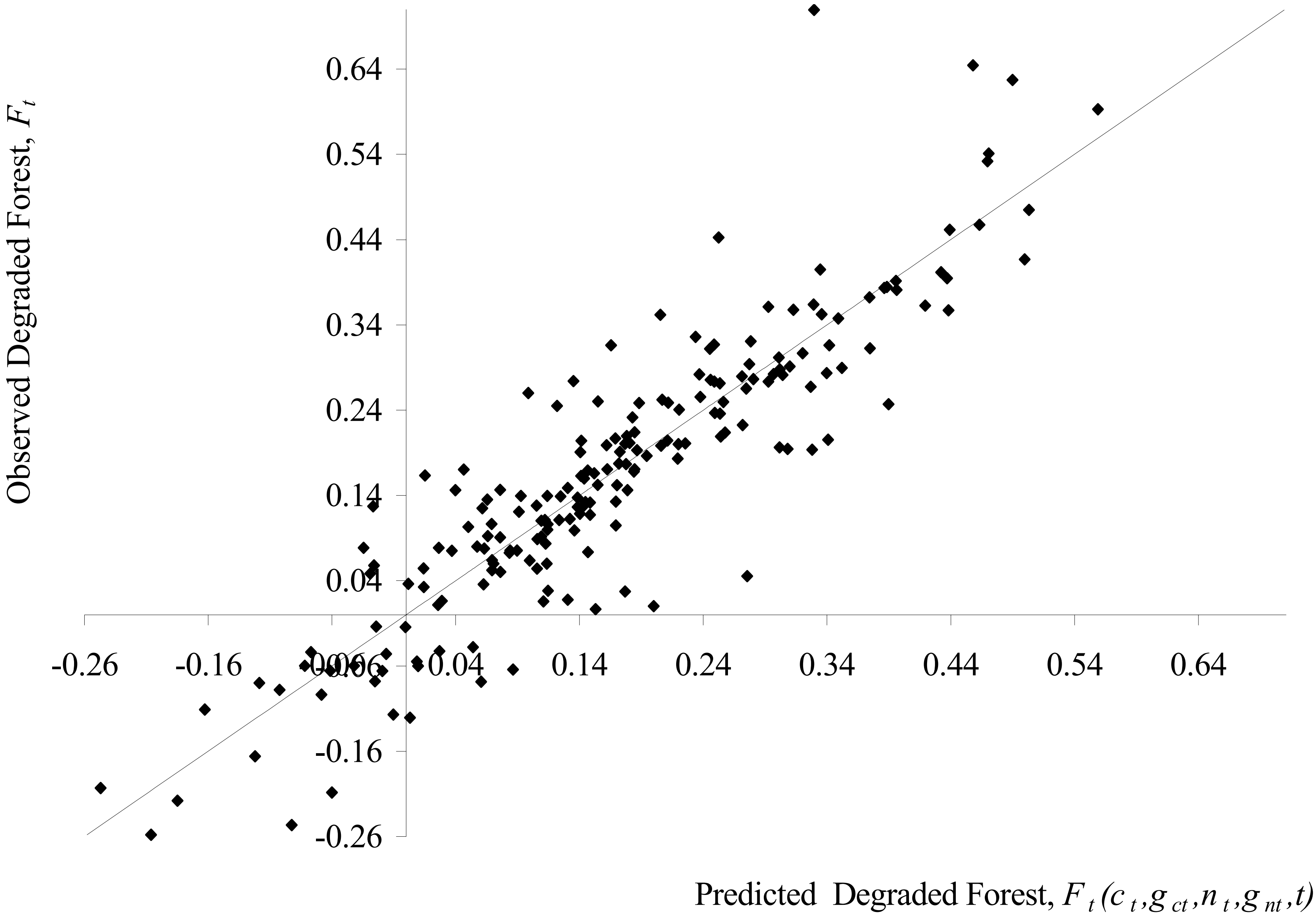


Forest Naturalness by
Survey Unit,
interpolated to 1981

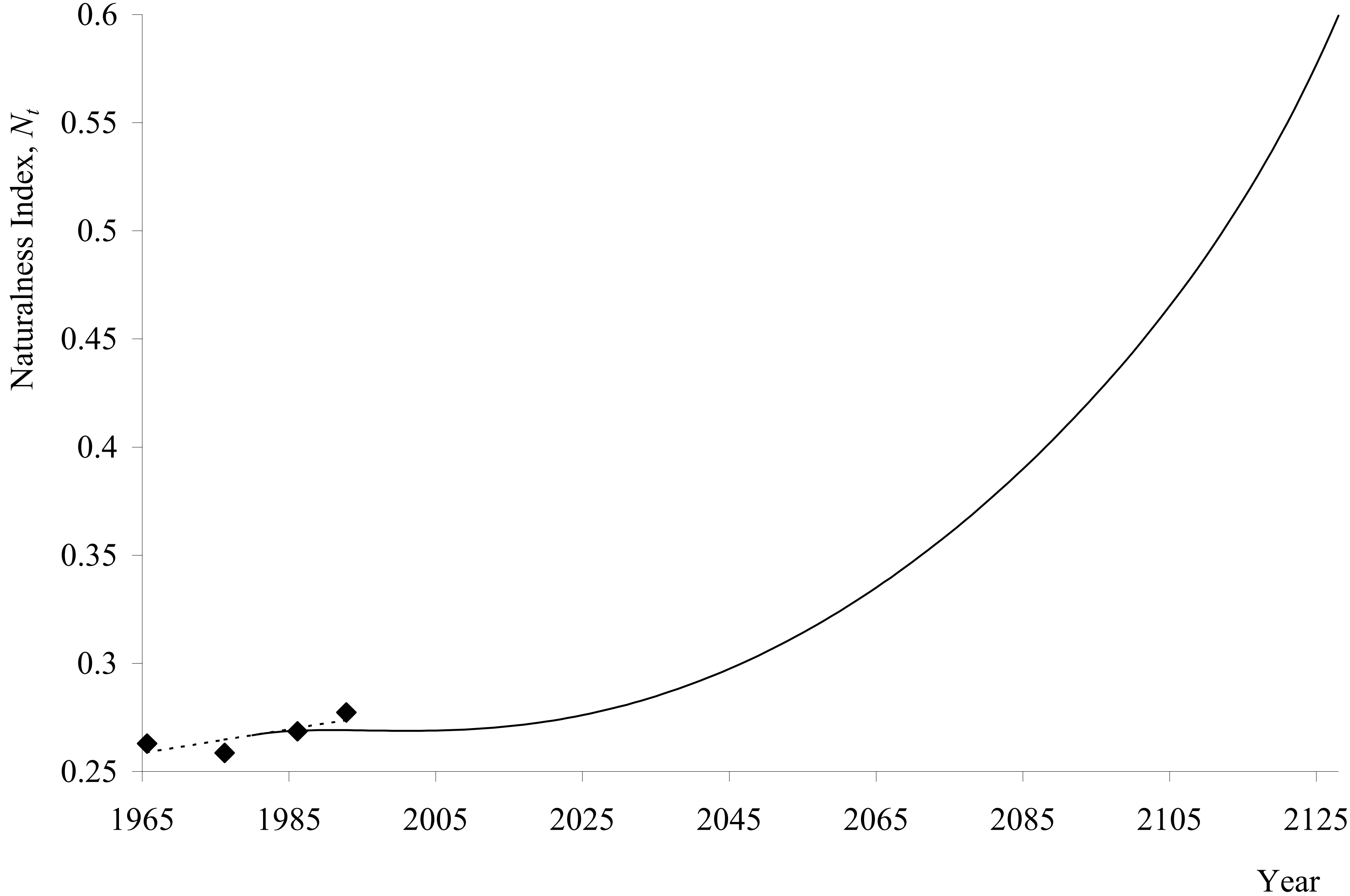
Forest Quality Trend vs. Income

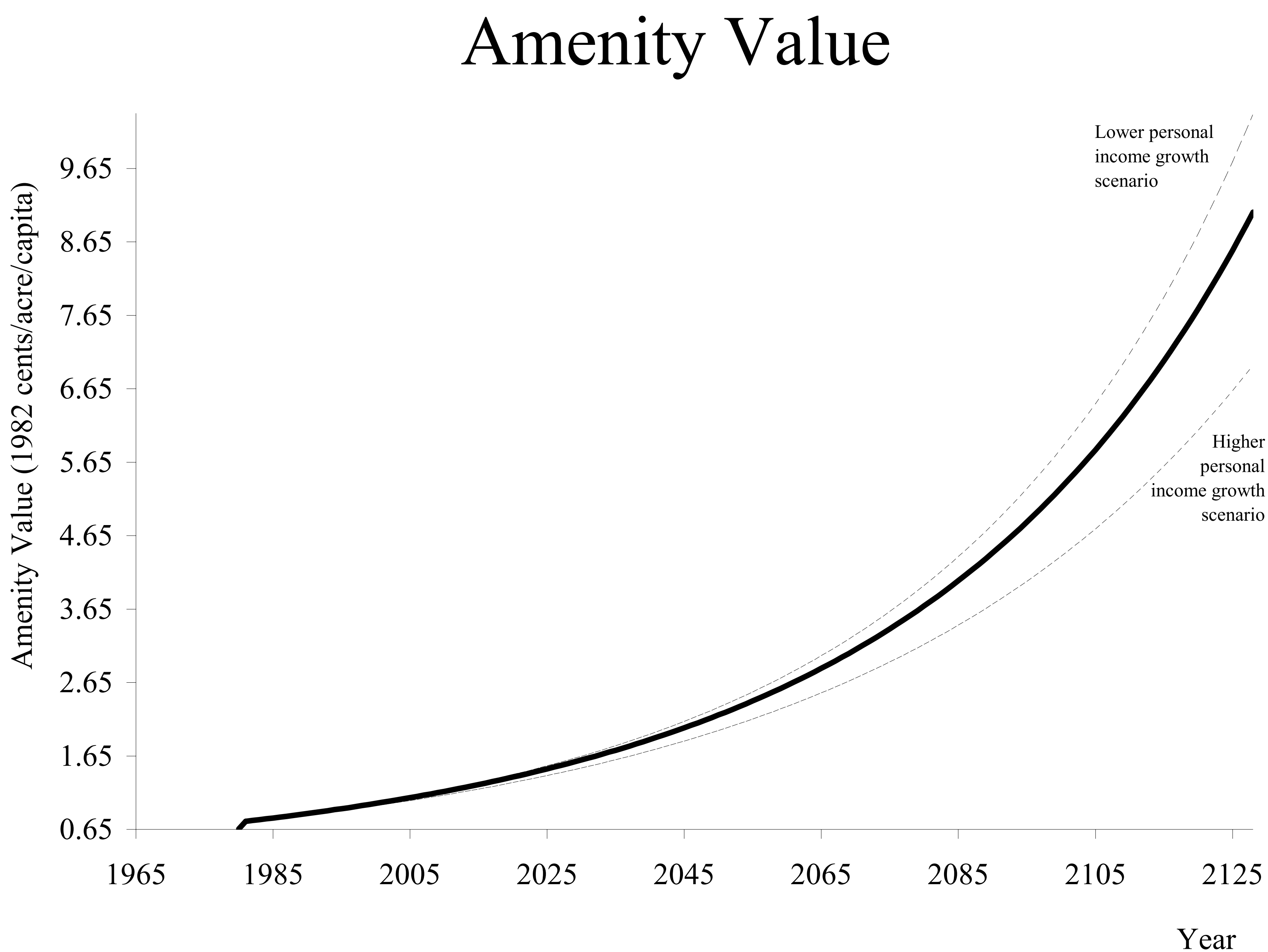


Stokey Model

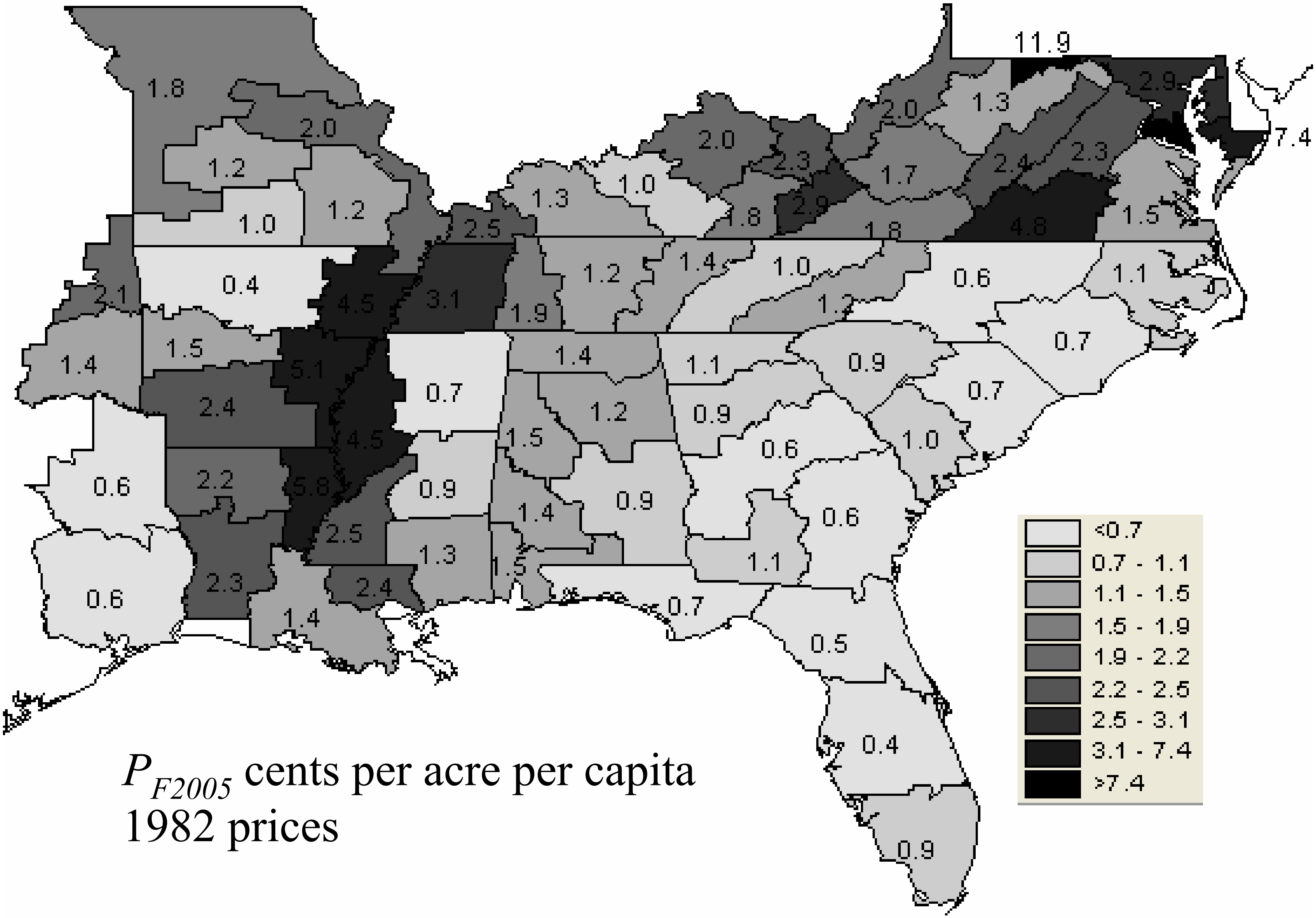


Model of Forest Naturalness Trend




Amenity Value
Amenity Value (1982 cents/acre/capita)
9.65
8.65
7.65
6.65
5.65
4.65
3.65
2.65
1.65
0.65
1965
1985
2005
2025
2045
2065
2085
2105
2125
Year
Lower personal income growth scenario
Higher personal income growth scenario

Per Capita Amenity Value, 2005



P_{F2005} cents per acre per capita
1982 prices

Effects of variables on amenity price

	Amenity per capita	Total Amenity
N_t	34 (14)*	265968 (76441)*
N_t^2	-40 (17)*	-305644 (91591)*
N_t / N_{t-1}	-0.5 (0.3)*	-3011 (1374)*
n_t (10^{-4})	-0.008 (0.002)*	29 (12)*
g_{nt}	-0.8 (0.4)**	-9523 (2270)*
c_t	0.0004 (0.0001)*	6 (0.6)*
g_{ct}	-3 (1)*	-10848 (6655)

Conclusions

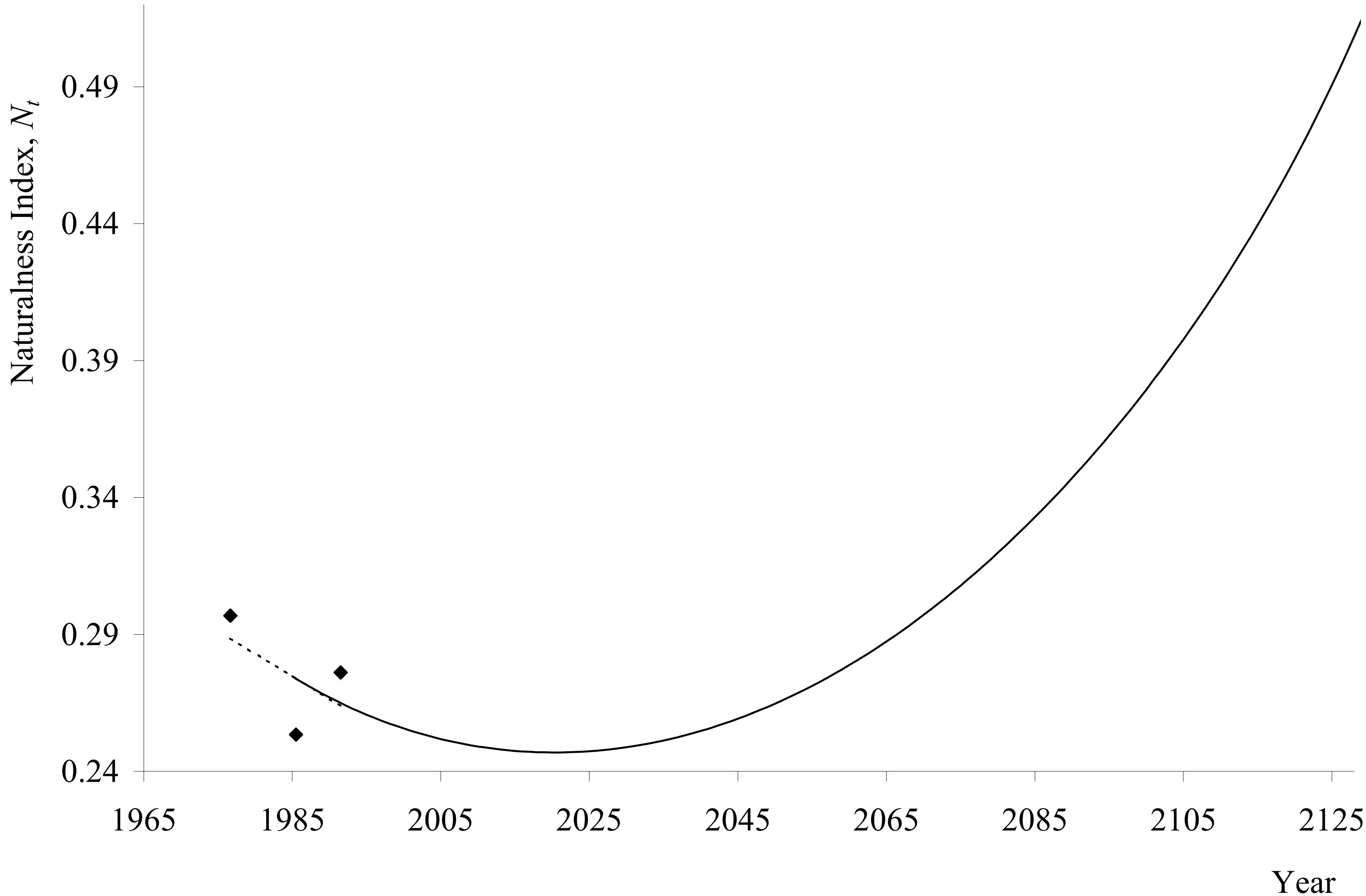
- Forest Amenity Value to Society
  - 1.0 to 2.3 cents per person
  - $6,280 to $17,300 per acre
- Forest Amenity Value to Landowner
  - $2,010 per acre
- Landowners pay more than average
- Landowners pay only part of the total
  - Classic under-provision of a public good

Acknowledgements

The research leading to this paper was supported in parts by the USDA Forest Service, Southern Forest Experiment Station, by the PREISM program of USDA-ERS, by CSREES-NRI grant 2001-35108-10673, by McIntire-Stennis grants 4879 and WIS 04456, and by the School of Natural Resources, University of Wisconsin, Madison.

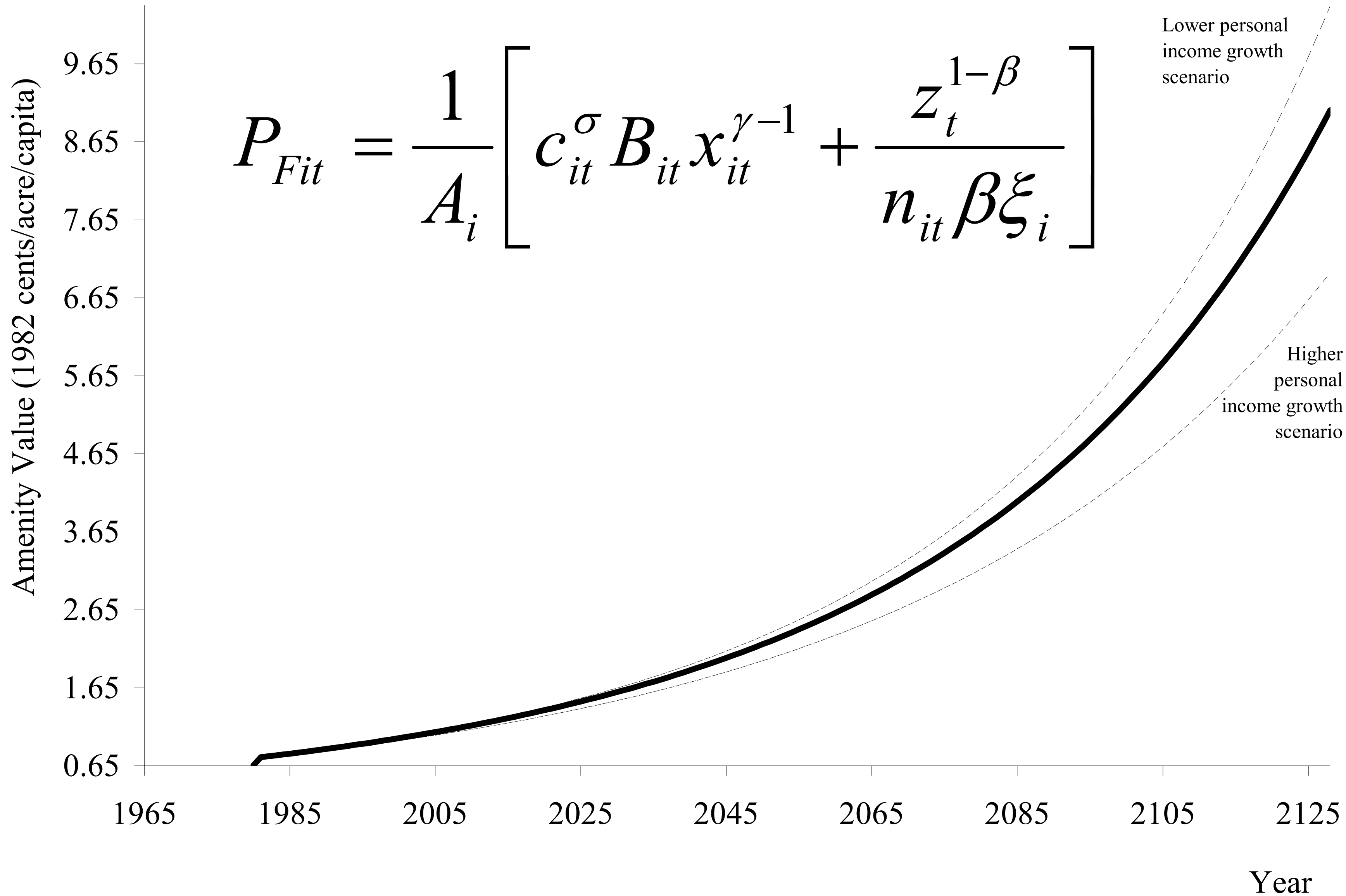
I thank Jeff Prestemon for his support and collaboration. I thank Volker Radeloff and Todd Hawbaker for identifying ecoregions of FIA plots. And, most of all I thank Joseph Buongiorno for his extensive help and expertise that made my program of research possible.

A Different Survey Unit, VA2



Amenity Value

$$P_{Fit} = \frac{1}{A_i}\left[c_{it}^{\sigma} B_{it} x_{it}^{\gamma-1} + \frac{z_t^{1-\beta}}{n_{it}\beta\xi_i} \right]$$



Why Assess Amenity Values?

- “Ignoring” non-market values assigns the very precise but inaccurate value of zero
- Amenities are increasingly valuable in an affluent economy
- Lord Kelvin
  - "To measure is to know "
  - "If you can not measure it,
    you can not improve it."

Non-Market Valuation Techniques

- Household Production Function
  - e.g. Travel Cost Method
- Hedonic Pricing
- Contingent Valuation

Naturalness Index

- Increases with tree diversity
  - Species
  - Size
- Decreases with exotic species prevalence
- Increases up to natural forested area
- Increases for more natural successional stages

EKC for Natural Forests

- Improving trend proves EKC
- Worsening part of the EKC is well known
    - Greeley (1925) maps diminishment of natural forest in this region between 1620 and 1920
    - While income increased
        - For Georgia, North Carolina, South Carolina and Tennessee
            - $752/capita in 1720 (Mancall, Rosenbloom and Weiss, 2000)
            - $1986/capita in 1929 (BEA data)
- Methods for monotonic trend are robust
- Correcting for regional differences less problematic
- This new method has broad application
    - SO_2 improving trend with income found
    - Obviously SO_2 pollution low before industrial revolution

Forest Amenity Value

$$P_{Fit}\left\{x_{it}, c_{it}, g_{cit}, n_{it}, t, A_i \middle| \beta, \gamma, \sigma, g, \xi_i, B_{it}, \delta, d\right\}$$

- Six variables
- Eight parameters
  - Additional parameter η_i

Difference Regression Implied by Model

$$
\begin{aligned}
\Delta \ln\left(x_{i,t+1}\right) = \quad & a_1(\gamma,\sigma)\frac{\Delta c_{it}}{c_{it}} \\
& + a_2(\beta,\gamma)\Delta f_t^1\left(g_{cit}\right) \\
& + a_3(g)\Delta t \\
& + a_4(\gamma)\left(\Delta f_t^2\left(g_{cit}, g_{ni,t+1}\right) - \frac{\Delta n_{i,t+1}}{n_{i,t+1}}\right) \\
& + \varepsilon_{it}
\end{aligned}
$$

Parameters Common to All Survey Units, i

g	Technology growth (yr^{-1})
β	Elasticity of forest degradation with respect to technology choice
γ	Elasticity of amenity utility with respect to stock of degraded forest
σ	Elasticity of consumption utility with respect to dollars of consumption
d	Social discount factor (yr^{-1}) $d=1/(1+r)$, where r is the social discount rate
δ	Depreciation of Capital (yr^{-1})

Parameters Specific to a Survey Unit

B_{it}	Scales amenity utility in consumption utility units
η_i	Natural recovery of forests (yr^{-1})
ξ_i	Scales destructiveness of technology choice to degraded forest units

B_{it} Identification

- Consumption curve, c_{it-1}, c_{it}
- Change in shadow value of forest amenities, μ_{it-1}, μ_{it}
- Disutility of degraded forests, x_{it}
- Thus, B_{it} implied

$$B_{it} d x_{it}^{\gamma-1} = \mu_{it-1} - d\mu_{it}\left(1-\eta_i\right)$$

ξ_i Identification

$$\xi_i \left[n_{it} g^{(t-1969)} k_{it} z_{it}^{\beta} \right]_{t=t_0} = \left(x_{i,t+1} - x_{it} (1-\eta_i) \right) \Big|_{t=t_0}$$

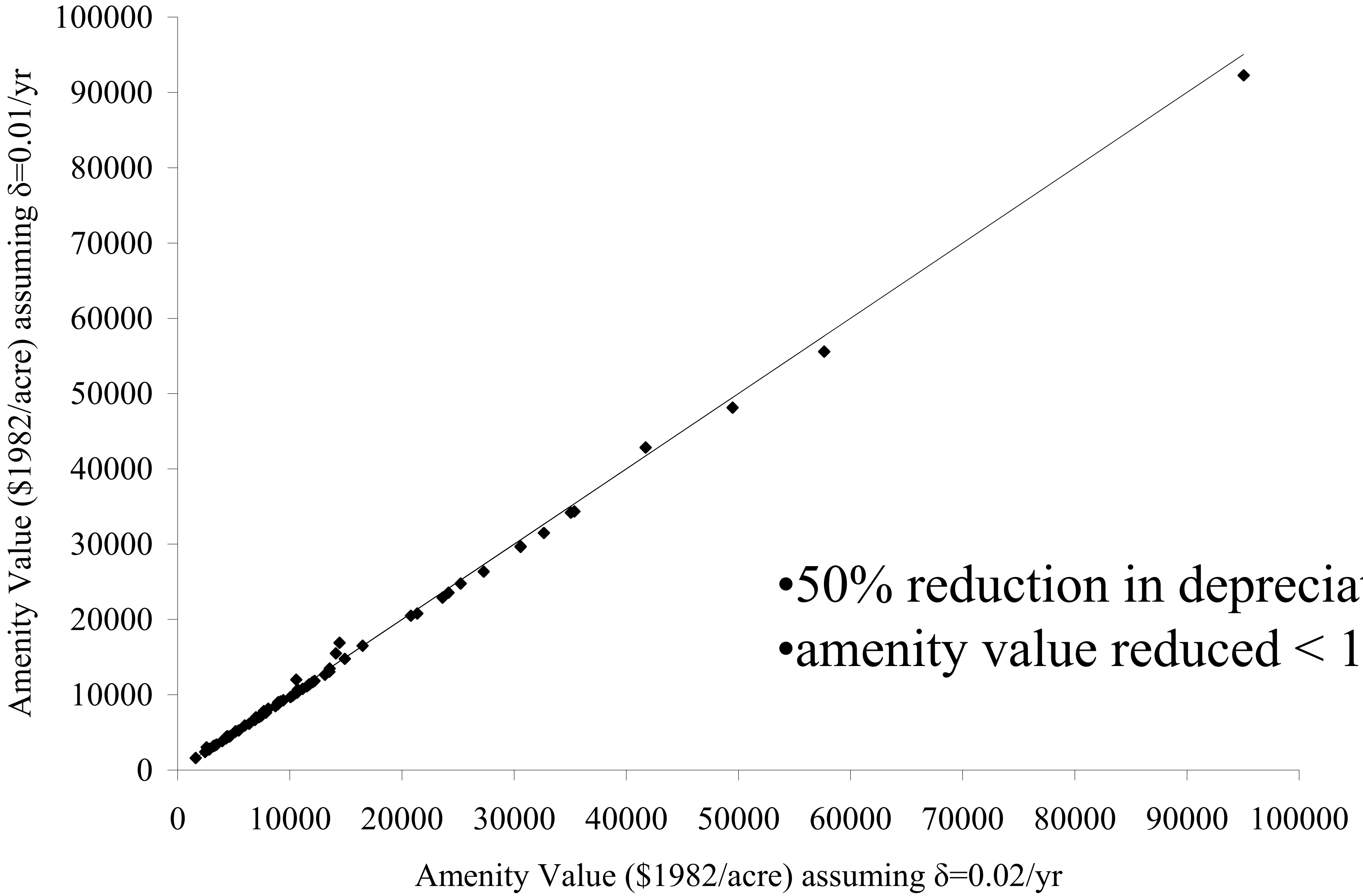
η_i Identification

$$\underset{\eta_i}{Min}\left\{\sum_{t=t_0+1}^{t_0+150}\left[B_{it}\left(c_{it}, z_{it}, x_{it}, n_{it}, \eta_i\right) - \sum_{t=t_0+1}^{t_0+150} B_{it}\left(c_{it}, z_{it}, x_{it}, n_{it}, \eta_i\right)/150\right]^2\right\},$$

s.t.

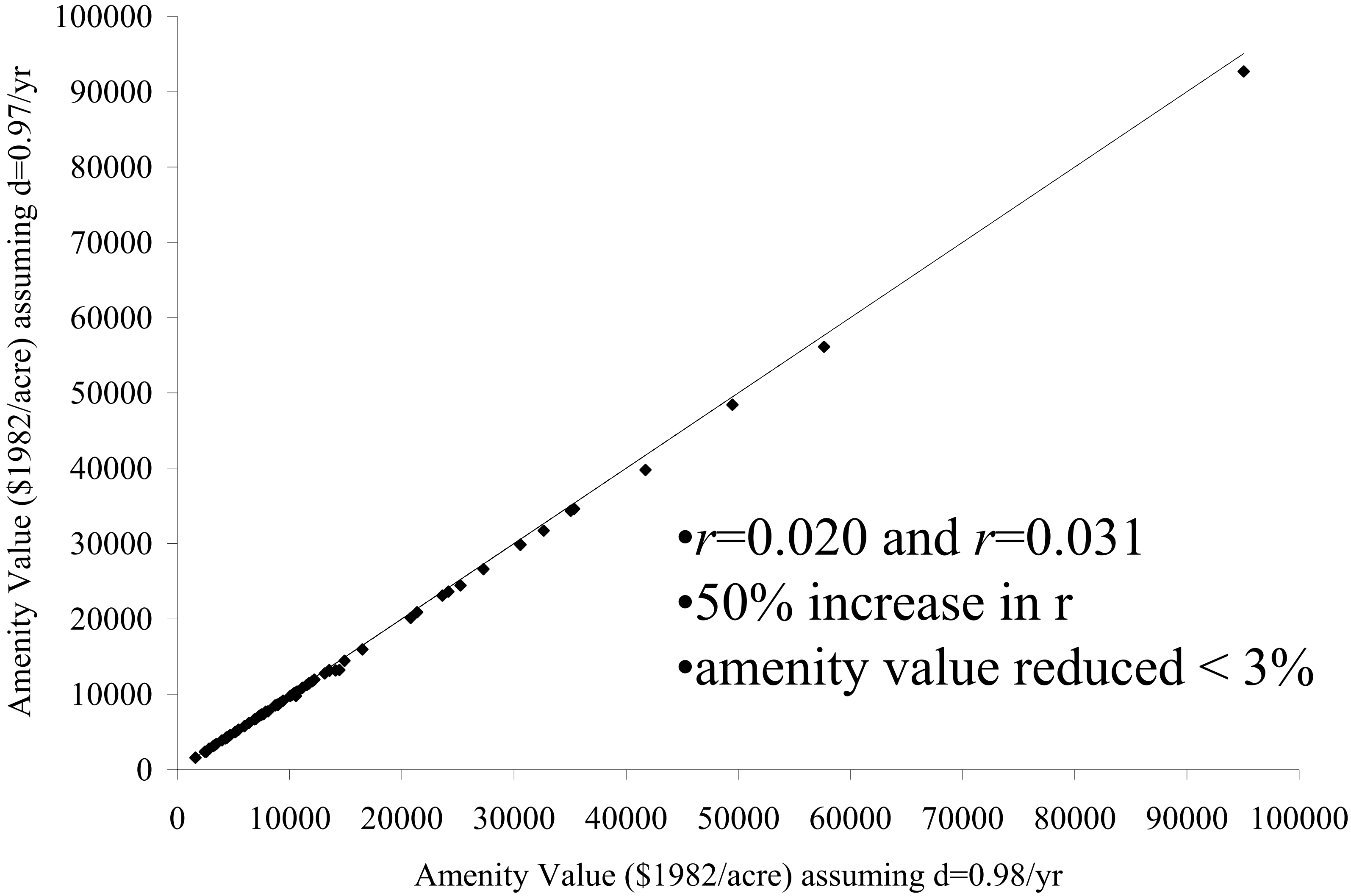
$\eta_i \in [0.05, 0.20].$

Capital Depreciation, δ



- 50% reduction in depreciation
- amenity value reduced < 1.6%

Social Discount Factor, d

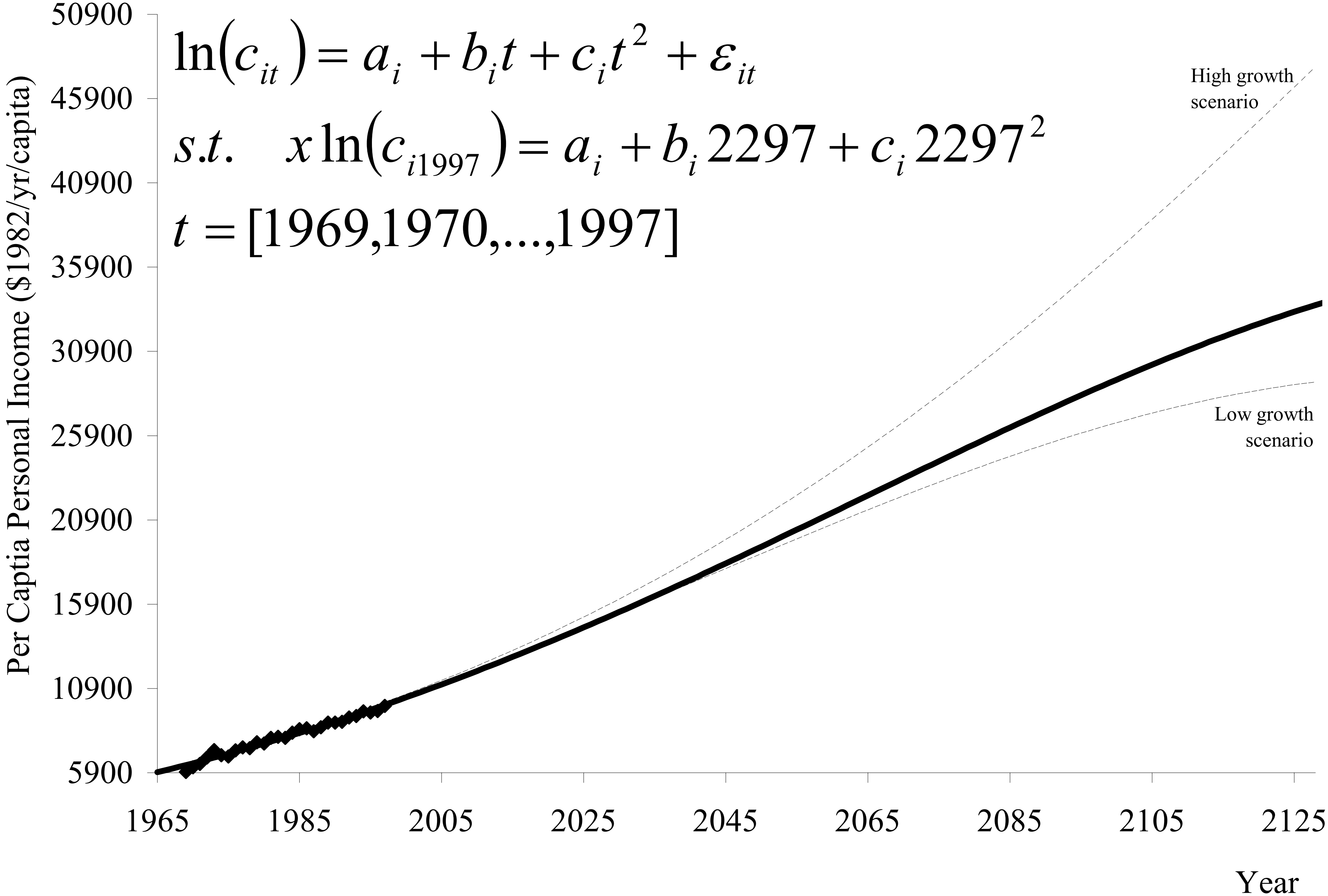


Per Capita Income Projection

$$\ln(c_{it}) = a_i + b_i t + c_i t^2 + \varepsilon_{it}$$

$$s.t. \quad x\ln(c_{i1997}) = a_i + b_i 2297 + c_i 2297^2$$

$$t = [1969, 1970, \ldots, 1997]$$

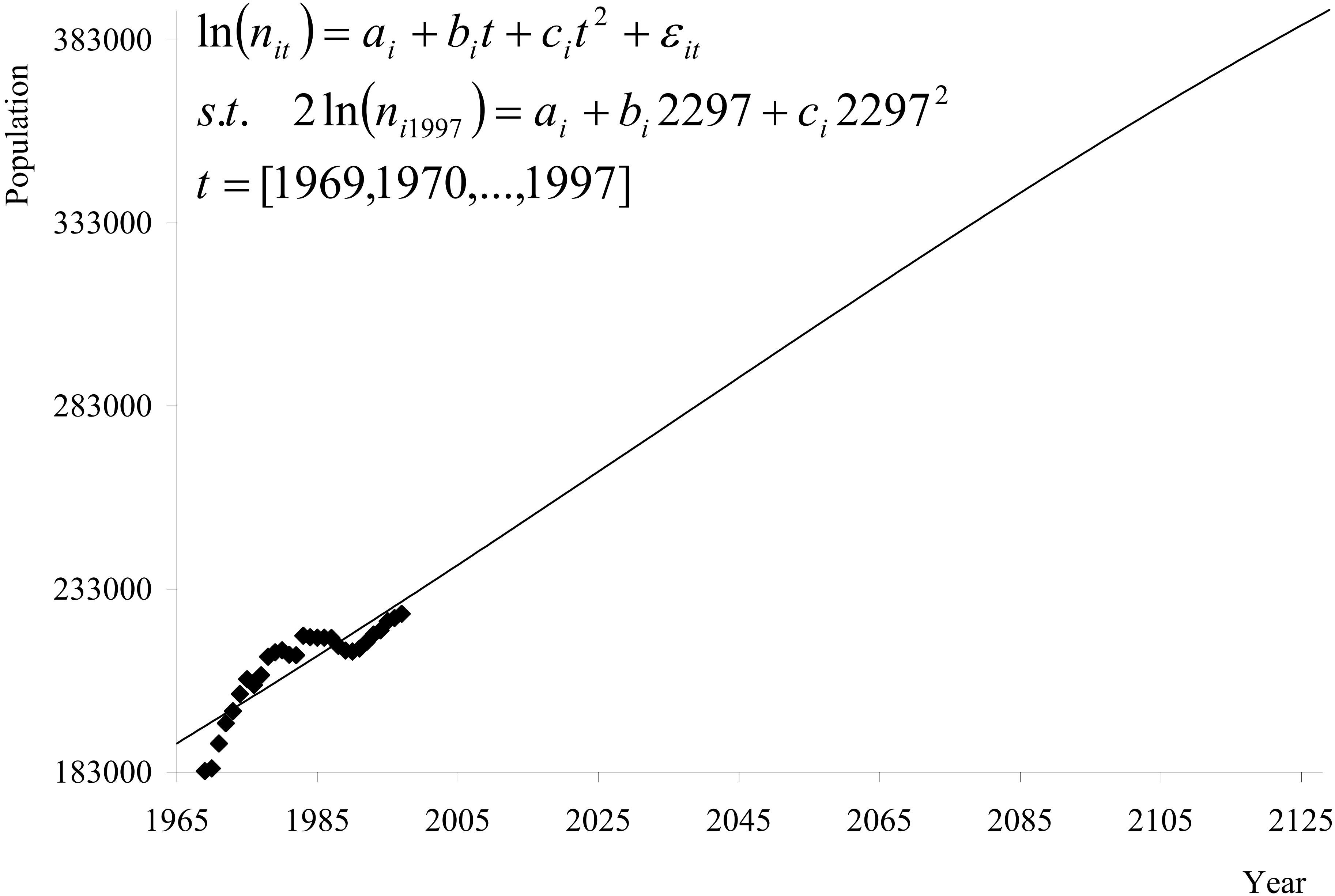


Population Projection

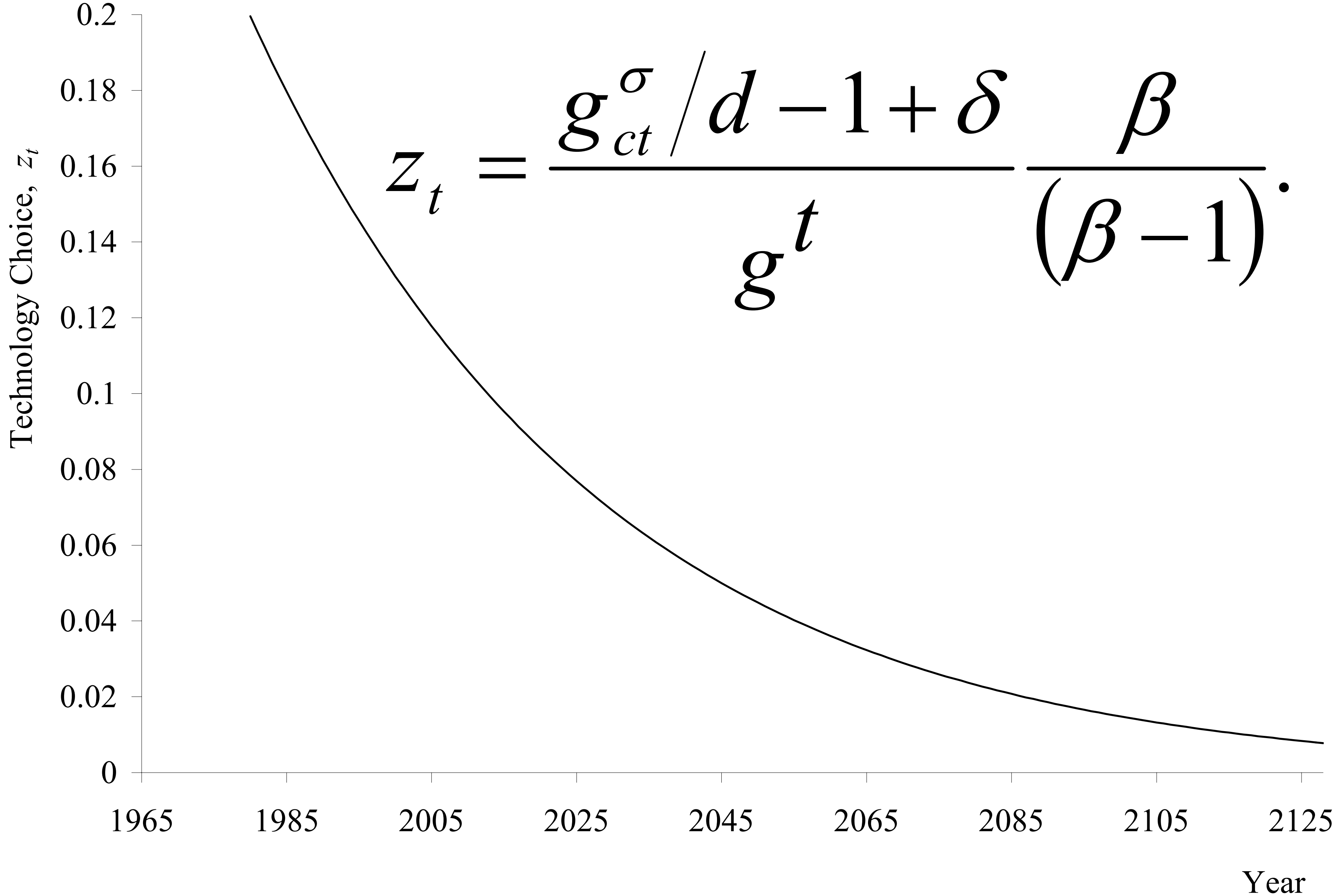
$$\ln(n_{it}) = a_i + b_i t + c_i t^2 + \varepsilon_{it}$$

$$s.t. \quad 2\ln(n_{i1997}) = a_i + b_i 2297 + c_i 2297^2$$

$$t = [1969, 1970, \ldots, 1997]$$



Technology Choice, z_t

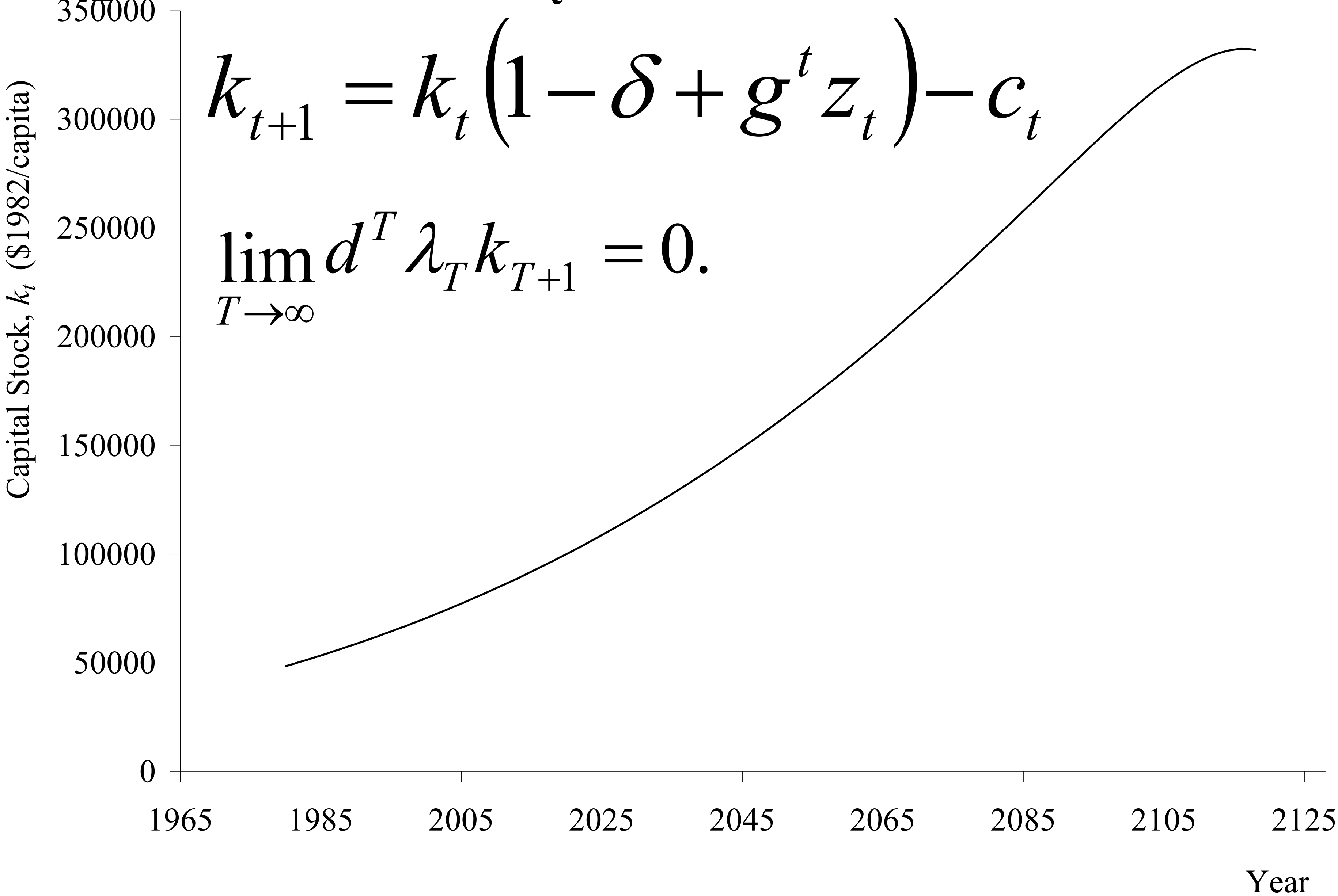


$$z_t = \frac{g_{ct}^{\sigma}/d - 1 + \delta}{g^t} \frac{\beta}{(\beta - 1)}.$$

Capital Stock, k_t

$$k_{t+1} = k_t\left(1 - \delta + g^t z_t\right) - c_t$$

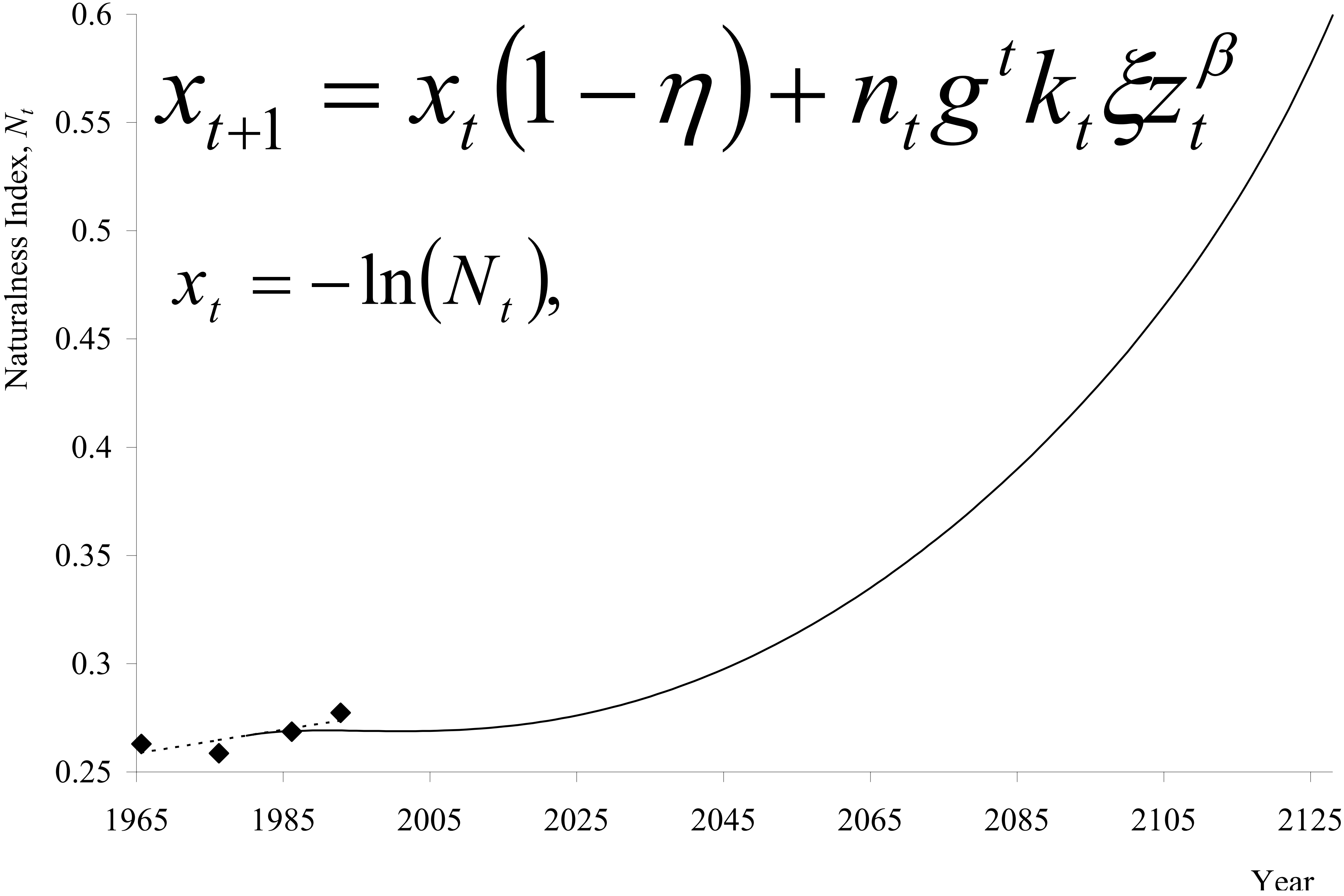
$$\lim_{T\to\infty} d^T \lambda_T k_{T+1} = 0.$$



Degraded Forest and Naturalness

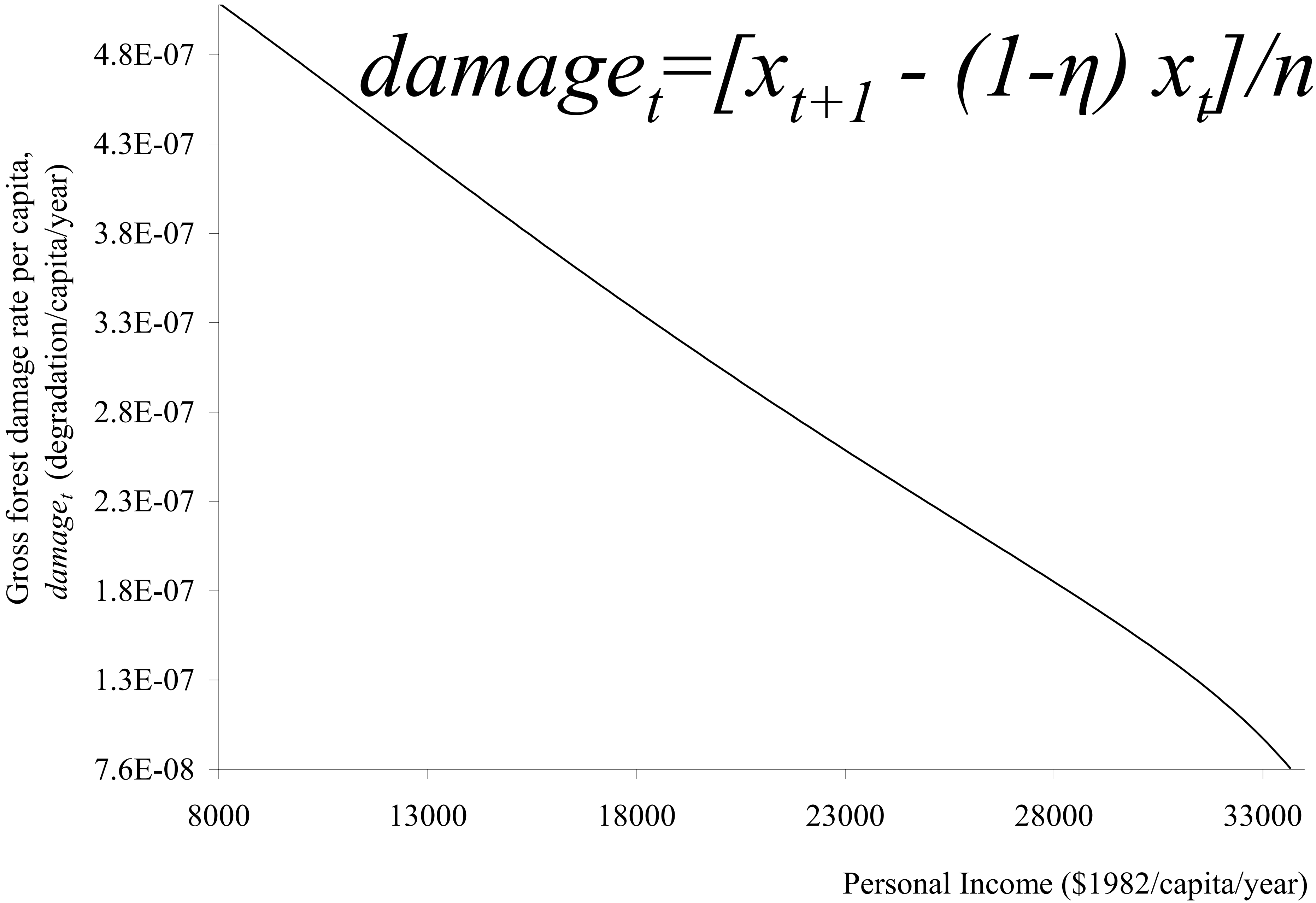
$$x_{t+1} = x_t(1-\eta) + n_t g^t k_t \xi z_t^{\beta}$$

$$x_t = -\ln(N_t),$$

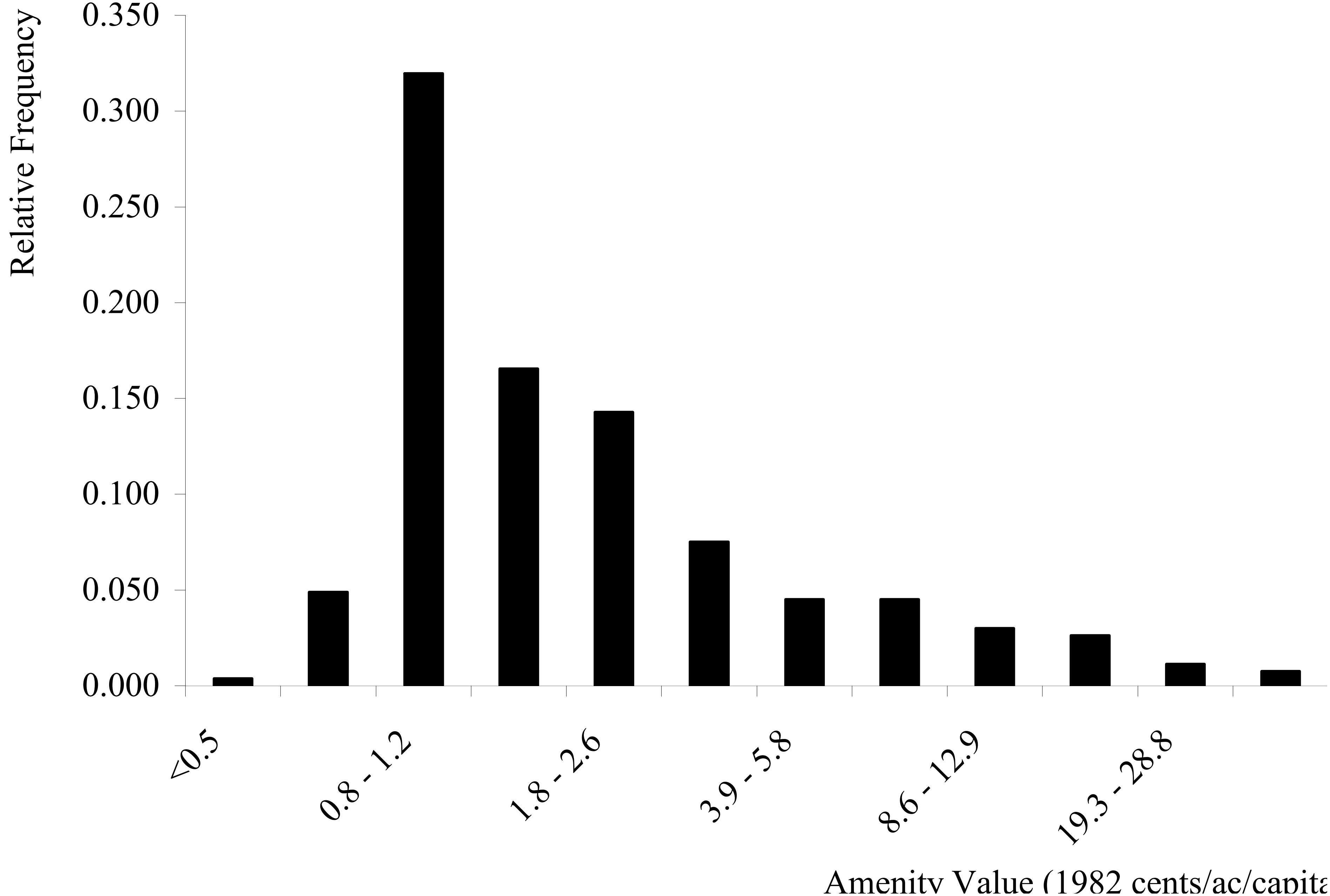


Gross Forest Damage per Capita EKC

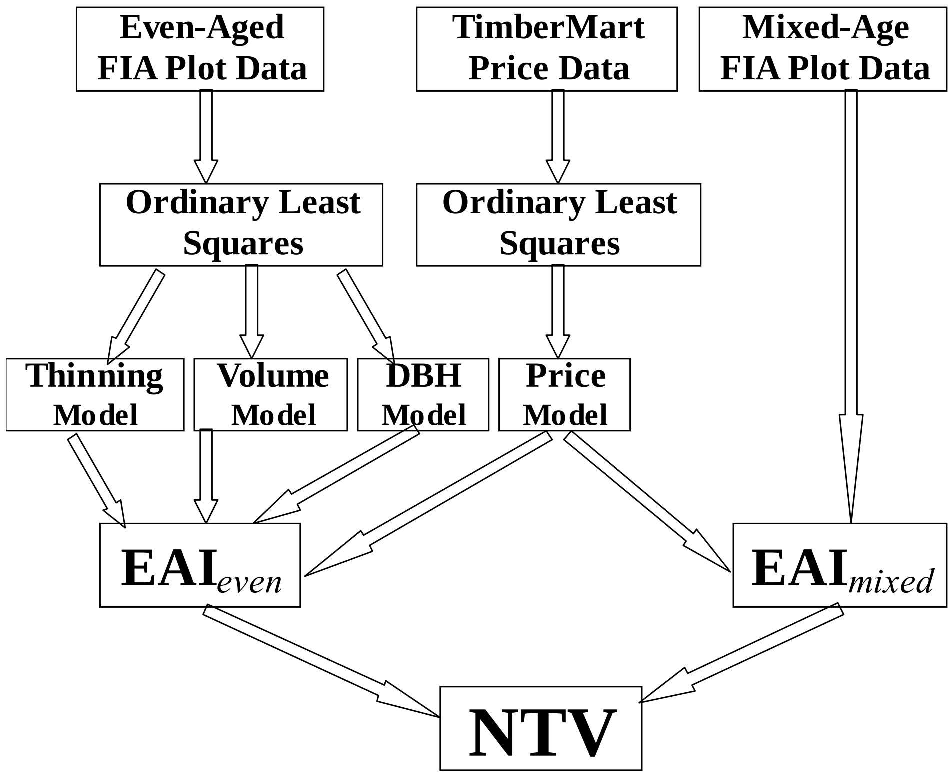
$$damage_t = [x_{t+1} - (1-\eta)\, x_t]/n_t$$



Amenity Value Distribution



Non-Timber Value (NTV)



Data

- Mixed-Age
  - 991 SoFIA plots
    - mixed-age
    - mixed-species
    - naturally regenerated
    - NIPF, industrial, and public ownership
- Even-Aged
  - 414 SoFIA plots

Data

- Mixed-Age
  - 991 SoFIA plots
- Even-Aged
  - 414 SoFIA plots
    - even-aged
    - loblolly pine plantations
    - artificially generated
    - industrially owned

Equivalent Annual Income

$$EAI = NPV \frac{(e^{r} - 1)e^{rt}}{e^{rt} - 1}.$$

- NPV = Net Present Value
- Equivalent Annual Income
  - Constant annual income during project with same value as NPV
  - Compare projects regardless of durations

Even-Aged EAI

$$EAI_{even} = \underset{R}{MAX}\left[NPV(X, m, R) \frac{\left(e^{r} - 1\right) e^{rR}}{e^{rR} - 1} \right].$$

- X = Site Characteristics
  - Site class, slope, aspect, physiography
- m = Timber market region
- R = Rotation, not observed

Single Rotation Even-Aged NPV

$$NPV(X, m, R) =$$

- Present discounted value of
  - Commercial thinning of pulp wood
  - Plus commercial thinning of saw logs
  - Plus final harvest
  - Minus planting costs

Single Rotation Even-Aged NPV

- Present discounted value of
  - Commercial thinning of pulp wood

$$\int_{t_p(X)}^{t_s(X)} -\dot{n}(X,t)\,v_T(X,t)\,p_p(m,t)\,e^{-rt}\,dt$$

  - Plus commercial thinning of saw logs
  - Plus final harvest
  - Minus planting costs

Single Rotation Even-Aged NPV

- Present discounted value of
  - Commercial thinning of pulp wood
  - Plus commercial thinning of saw logs

$$\int_{t_s(X)}^{R} -\dot{x}(X,t)\begin{bmatrix} v_s(X,t)p_s(m,t) \\ +\left(v_T(X,t)-v_s(X,t)\right)p_p(m,t) \end{bmatrix} e^{-rt}\,dt$$

  - Plus final harvest
  - Minus planting costs

Single Rotation Even-Aged NPV

- Present discounted value of
  - Commercial thinning of pulp wood
  - Plus commercial thinning of saw logs
  - Plus final Harvest

$$n(X,R)\begin{bmatrix} v_s(X,R)p_s(m,R) \\ +\left(v_T(X,R)-v_s(X,R)\right)p_p(m,R) \end{bmatrix}e^{-rR}$$

  - Minus planting costs

Even-Aged Management

- Stand thinning
- Volume growth
- Diameter growth
- Price expectations

Even-Aged Management

- Stand thinning

$$n(X,t) = EXP(\beta_n X - \alpha X t)$$

- Volume growth
- Diameter growth
- Price expectations

Even-Aged Management

- Stand thinning
- Volume growth

$$v_T(X,t) =$$

$$\beta_{vT} X + \alpha_{T1} X t + \alpha_{T2} X t^2$$

- Diameter growth
- Price expectations

Even-Aged Management

- Stand thinning
- Volume growth
- Diameter growth

$$d(X,t) =$$

$$\beta_d X + \alpha_{d1} X t + \alpha_{d2} X t^2$$

- Price expectations

Even-Aged Management

- Stand thinning
- Volume growth
- Diameter growth
- Price expectations

$$p_k = B_k^{1991} EXP\left[g_p\left(t - 1991\right)\right]$$

Econometrics

- NTV of each Mixed-Age Plot
  - EAI_{even}
  - Observed use of Even-aged plots
  - Linear regressions
  - Bootstrapped distribution

Stokey Model

*Maximize PDV future utility of
    *Consumption (c_t)
    *Forest amenities (related to degraded forest quantity x_t)
*Trade-off between
    *c_t
        *and
    *investment in capital (k_t) (for future consumption)
*Trade-off between production and x_t
    *Technology choice (z_t)
    *Larger z_t more production, more forest degradation
    *Price for less degradation is less production

Stokey Model

*Planners problem
    *Aggregates efficient markets

$$\underset{\{c_t, z_t\}}{Max} \sum_{t=0}^{\infty} d^t \{v(c_t) - w(x_t)\},$$

$$k_{t+1} - k_t + c_t \leq f(k_t) z_t,$$

$$x_{t+1} - x_t - nf(k_t)\Phi(z_t) + h(x_t) = 0,$$

$$k_{t+1} - k_t \geq 0,$$

$$z_t \in [0, z_{\max}].$$

Six Optimality Conditions

*Shadow Price of Consumption

$$\lambda_t = v'(c_t)$$

*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption

$$\nu(c_t) = \frac{c_t^{1-\sigma} - 1}{1-\sigma}, \qquad \sigma > 0.$$

$$\lambda_t = \nu'(c_t) = c_t^{-\sigma}$$

*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption

$$\lambda_t = d\left\{\lambda_{t+1}\left[1 + f'(k_{t+1})z_{t+1}\right] + n\mu_{t+1}f'(k_{t+1})\Phi(z_{t+1})\right\}.$$

*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption

$$\lambda_t = d\left\{\lambda_{t+1}\left[1 + f'\left(k_{t+1}\right)z_{t+1}\right] + n\mu_{t+1} f'\left(k_{t+1}\right)\Phi\left(z_{t+1}\right)\right\}.$$

$$f\left(k_t\right) = Ag^t k_t^{\alpha},$$

$A > 0,$

$g > 1,$

$0 < \alpha \leq 1.$

*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption

$$\lambda_t = d\{\lambda_{t+1}[1 + f'(k_{t+1})z_{t+1}] + n\mu_{t+1} f'(k_{t+1})\Phi(z_{t+1})\}.$$

$$\Phi(z_t) = \xi(z_t)^{\beta} \qquad \beta > 1.$$

*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth

$$k_{t+1} = k_t + f\left(k_t\right)z_t - c_t.$$

*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests

$$x_{t+1} = x_t + nf(k_t)\Phi(z_t) - h(x_t).$$

*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests

$$x_{t+1} = x_t + nf(k_t)\Phi(z_t) - h(x_t).$$

$$h(x_t) = \eta x_t \qquad \eta > 0.$$

*Opportunity Cost of Forest Degradation
*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation

$$\mu_t = d\left\{-w'\left(x_{t+1}\right) + \mu_{t+1}\left[1 - h'\left(x_{t+1}\right)\right]\right\}.$$

*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation

$$\mu_t = d\{-w'(x_{t+1}) + \mu_{t+1}[1 - h'(x_{t+1})]\}.$$

$$w(x_t) = \frac{Bx_t^{\gamma}}{\gamma}, \qquad \gamma > 1, \quad B > 0.$$

*Optimal Technology

Six Optimality Conditions

*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation

$$\mu_t = d\left\{-w'\left(x_{t+1}\right) + \mu_{t+1}\left[1 - h'\left(x_{t+1}\right)\right]\right\}.$$

$$N_t = EXP\left(-\rho x_t\right).$$

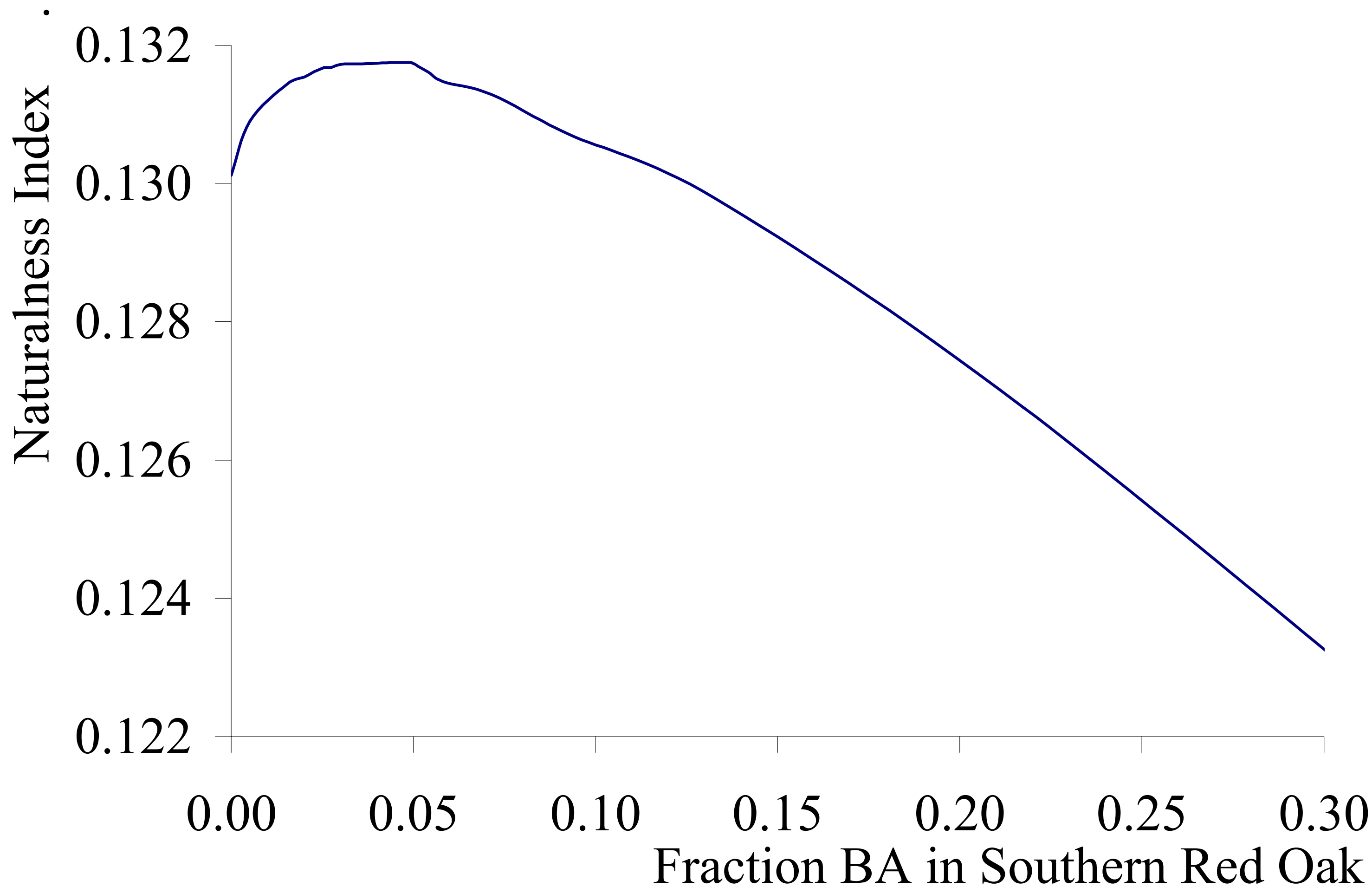
*Optimal Technology

Six Optimality Conditions

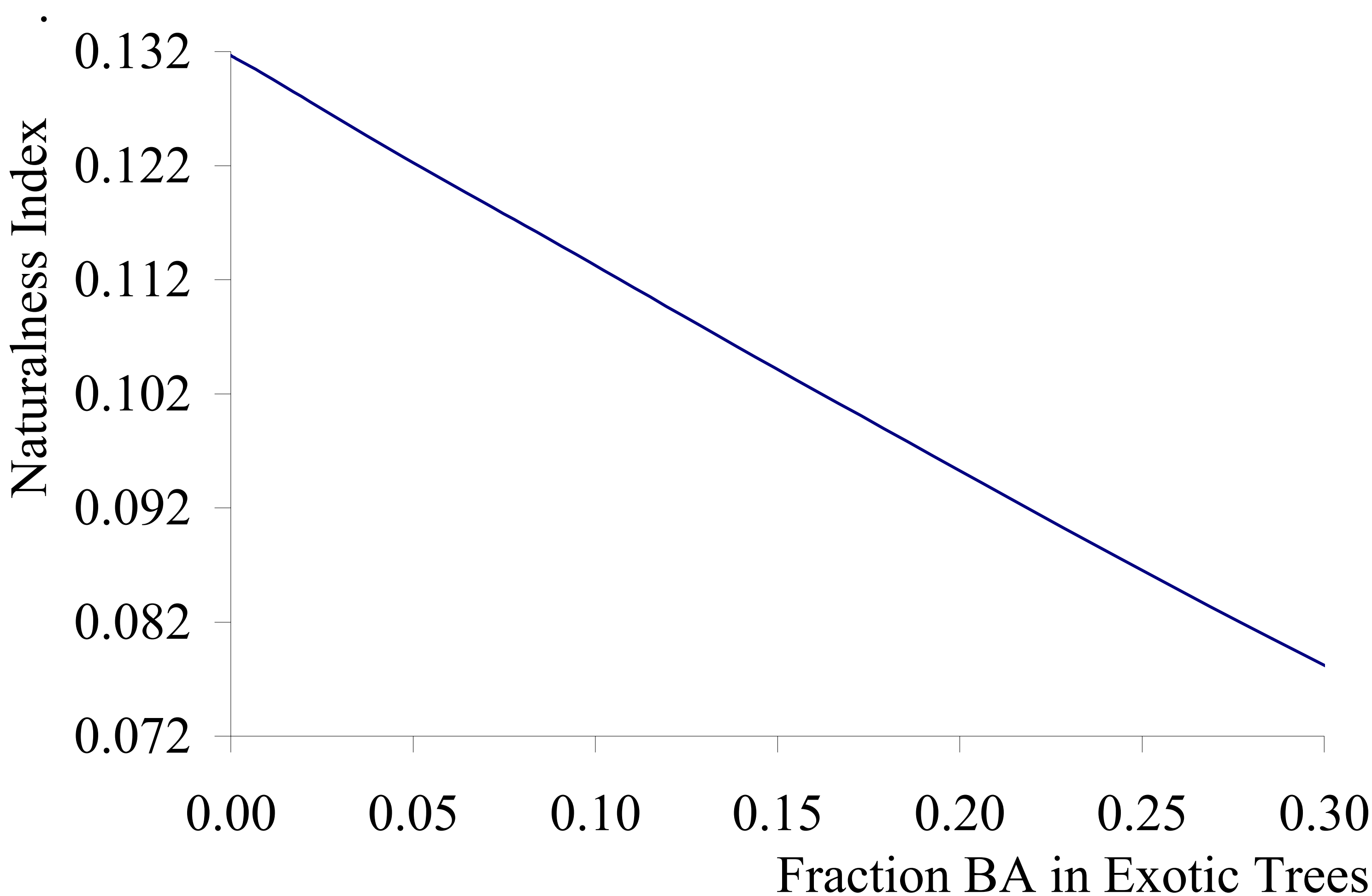
*Shadow Price of Consumption
*Opportunity Cost of Consumption
*Accumulation of Wealth
*Degradation of Forests
*Opportunity Cost of Forest Degradation
*Optimal Technology

$$\lambda_t f(k_t) = -n\mu_t f(k_t)\Phi'(z_t).$$

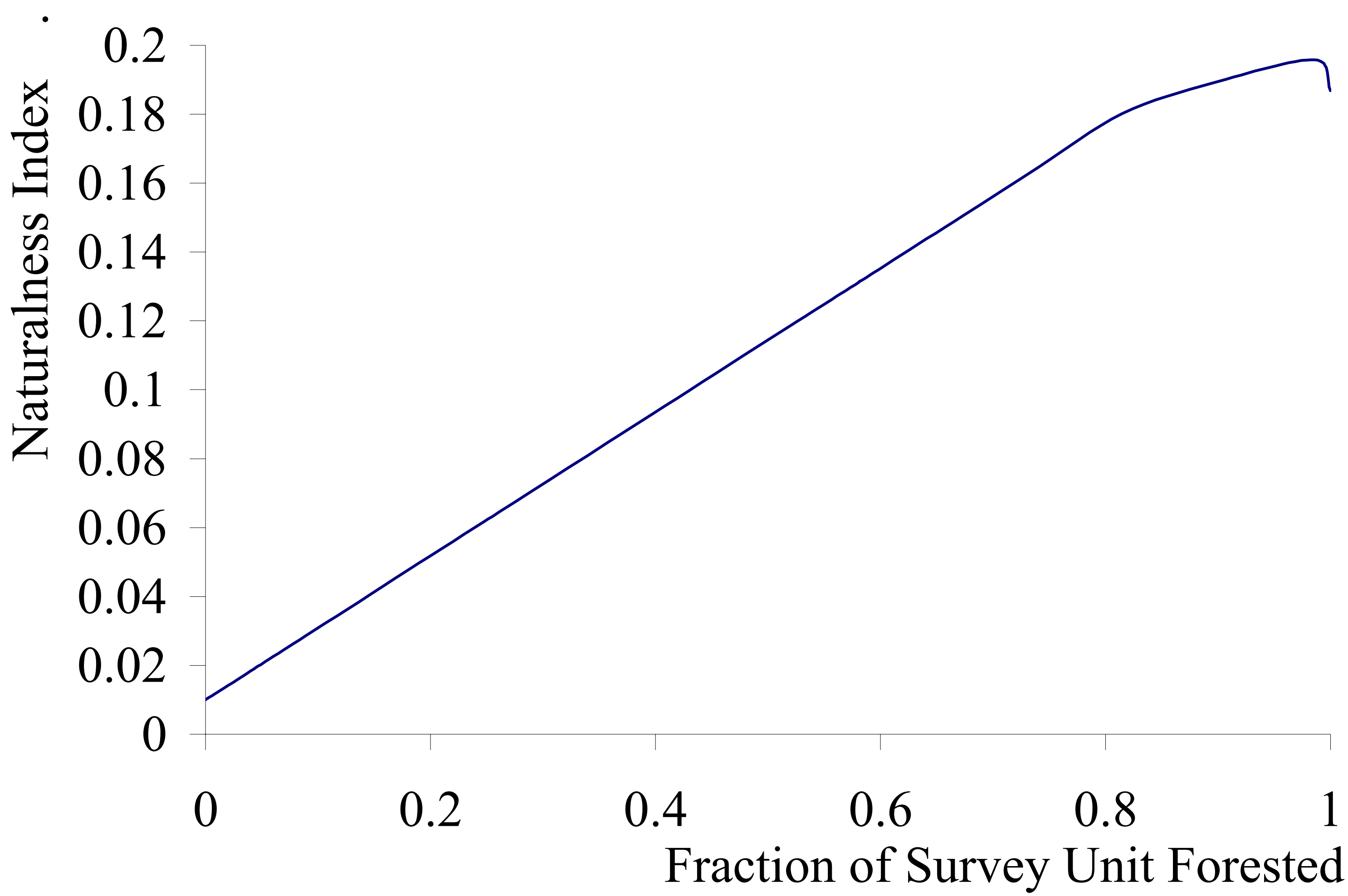
Increasing a Single Species



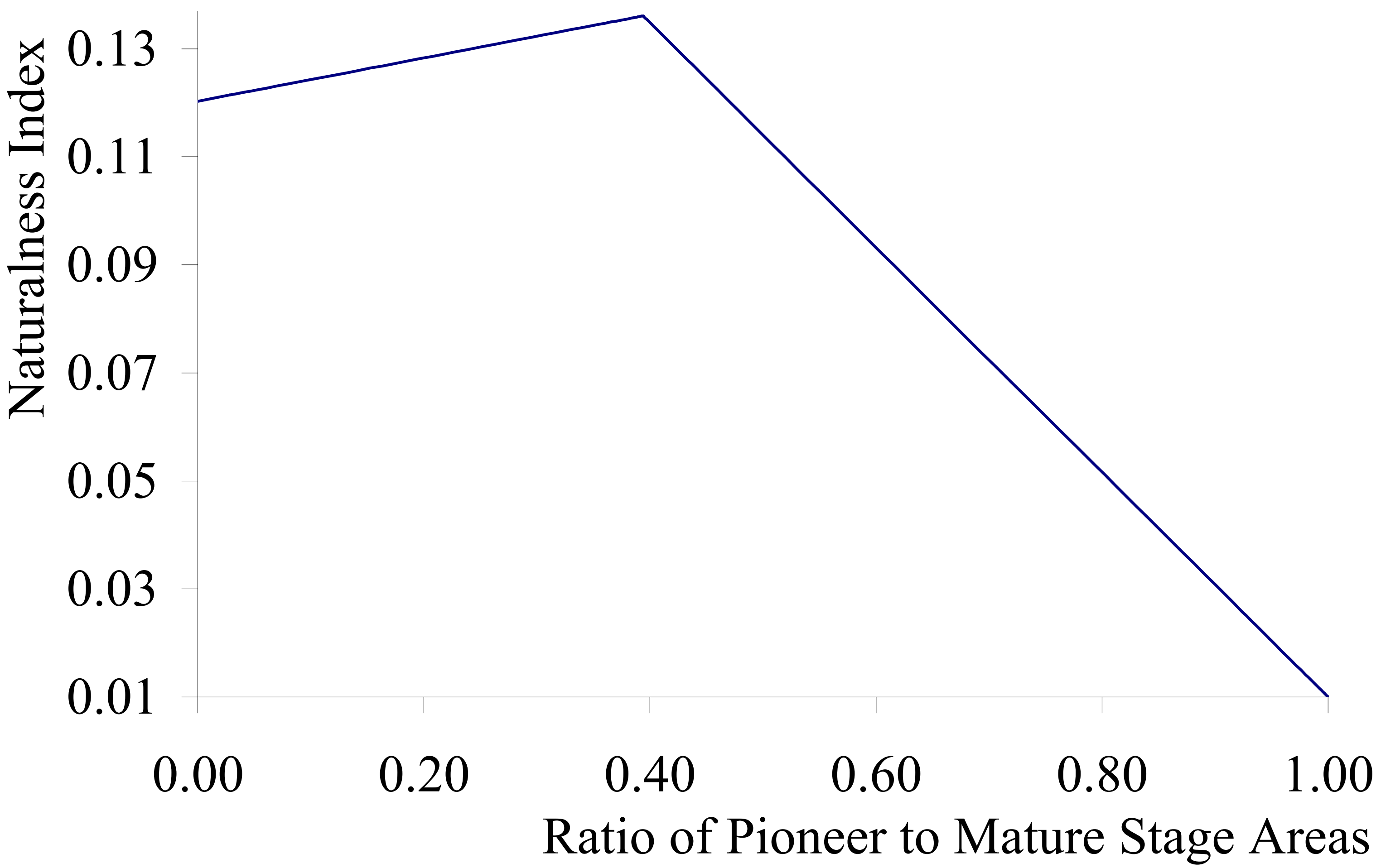
Increasing Exotic Species



Afforestation



Area in Early Succession Stage



Conclusion

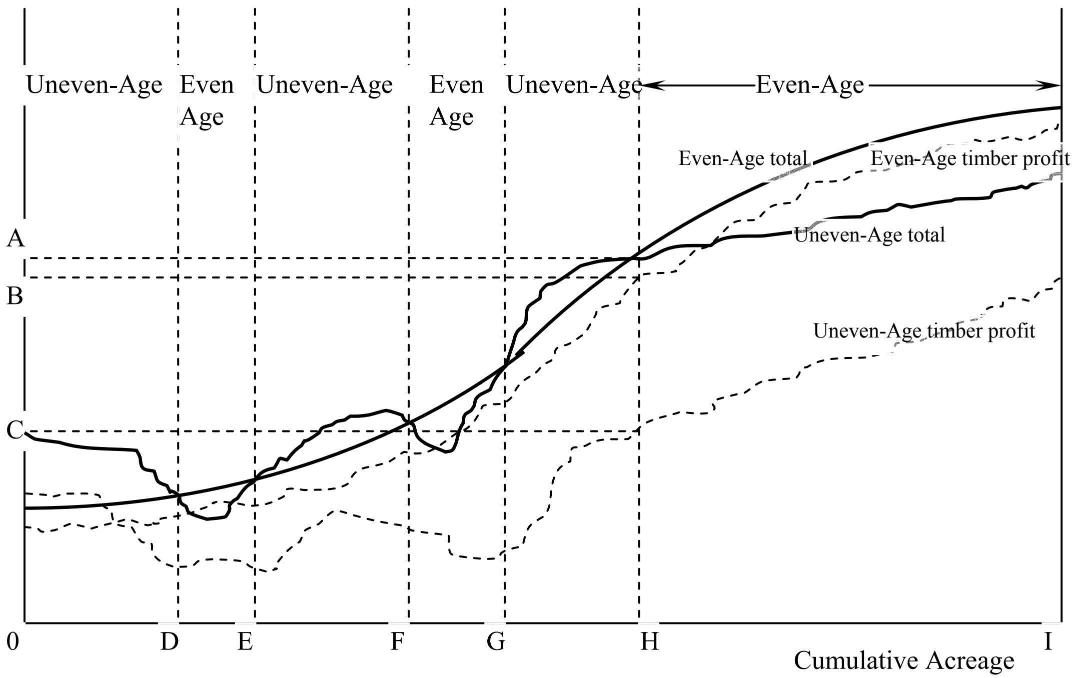
- Revealed preference methods defined
  - Individual behavior
  - Aggregate behavior
- Other methods defined
  - Even-aged profit estimation
  - Naturalness metric

Aggregate Regional Naturalness

$$N = \frac{1}{A}\sum_i \left\{ A_{im} \sum_j \left\{ f_{ij} Max\left[1, \frac{A_{ij}}{f_{ij} A_{im}} \right] S_{ij}^{P} S_{ij}^{R} \right\} \right\}.$$

Average Plot Diversity

$$S_{ij}^{P} = \sum_{k} \frac{A_{ijk}}{A_{ij}} \left[\frac{-1}{\ln\left(\sum_{l} p_{ijl} \right)} \sum_{l} \left(X_{ijkl} \ln\left(X_{ijkl} / p_{ijl} \right) \right) \right].$$



Assignment of timberland between two silvicultural systems.